The Effect of Flux Window Orientation on Beam Spectra

Robert Hatcher[1]

[1]rhatcher@fnal.gov – *Fermi National Accelerator Laboratory*

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1 Introduction

The standard "flux" files from the beam simulation (both using FLUGG and G4NUMI) have entries that represent the decay of an unstable particle (generally π, K and μ) into a neutrino. The ntuple entries have weights associated with them which when combined with the frequency in the file represent the probability of that chain of particles resulting in that decay. But to evaluate the actual flux of neutrinos through some region one must also account for the probability that the neutrino will be boosted in a particular direction.

There are a number of versions of the code to calculate the weight factor for going through a particular point in space (relative to the beam coordinate system) for a given entry. All are based on the same assumptions. Hidden in the calculation is a normalization for the "per unit area". When spectra are calculated for a single infinitesimal point this doesn't matter. But when the calculation is for an extended area then the orientation of the window relative to the beam will have an effect.

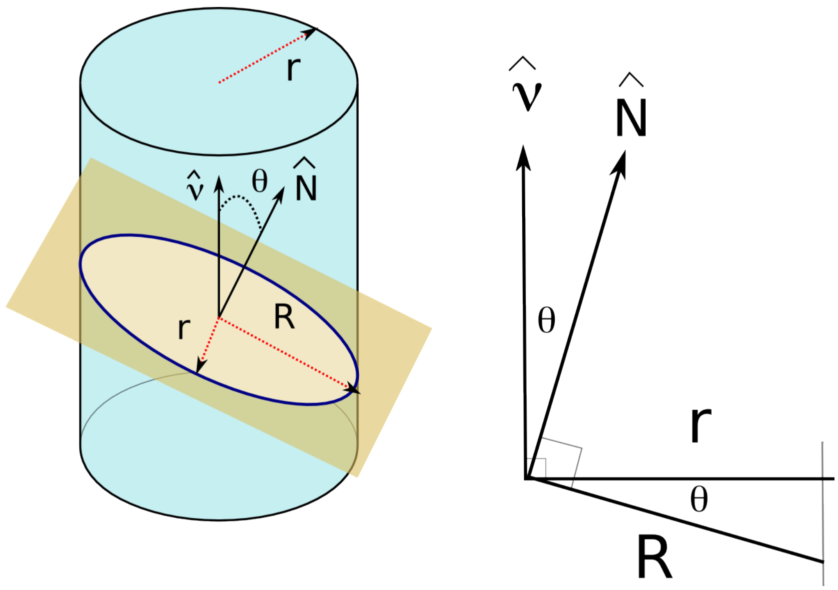
To minimize the overhead in evaluating the flux these files are used to produce a series of "rays" that intersect the geometry; rather than repeatedly picking a single point in space and evaluating the probability for that single point the procedure is to pick an initial starting point and follow the path of the ray through the geometry elements downstream of that point. This reduces the number of evaluations of a weight that must be generated and smooths out the effect of density variations in the geometry, but it requires a choice for the surface for the initial evaluation.

When choosing an entry from the flux file and evaluating the resulting ray originating at a point in space there is an implicit assumption that that ray is associated with a unit area orthogonal to the ray. When points to evaluate are chosen from an area that is not orthogonal to the ray, then an oversampling is done proportional the the relative areas swept out as shown in Figure 1. If points are being chosen on the ellipse, then the ratio (weight to apply) is:

$$w = \frac{\pi r^2}{\pi r R} = \frac{r}{R} = \cos\theta = \hat{\nu} \cdot \hat{N}$$

where $\hat{\nu}$ is the direction of the neutrino ray and $\hat{N}$ is the normal for the surface where points are chosen.

Figure 1: The intersection of a ray (with associated cylindrical volume) and an plane.



For the GENIE flux drivers `GNuMIFlux` and `GDk2NuFlux` the window is the area swept out by the sum of two vectors in space relative to an origin point; normally those vectors are orthogonal to each other but only in the far field case can they be orthogonal to the beam as a whole. In NOνA the *flux window* surface has traditionally been declared to be parallel to the front face of the detector. This puts it at roughly $3.3°$ (58 mrad) relative to the beam for the near and far detectors. In the NOνA NDOS case the flux has two significant sources: decays near the target, and decays from particles in the hadron dump. Unlike the near and far detectors those two sources have significantly different angular acceptances. This leads to a $2 - 10\%$ fall off at low energies. The rays coming from π and K decay at rest in the hadron absorber are particularly pronounced due to the large angle involved [1]. Figures 2 and 3 are for the flux and not for the event rate; as the cross section scales roughly with neutrino energy these plots over-emphasize the effect.

References

[1] Robert Hatcher. On NOνA Flux-Detector Coordinate Transformations. `https://nova-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=6636`.

Figure 2: The effect on NOνA near detector flux predictions. The lower plots are the ratio of the case where the effect is accounted for relative to the original code. Overall the effect is very small $\approx \cos(3.3\,\mathrm{deg}) \sim 0.99834$.

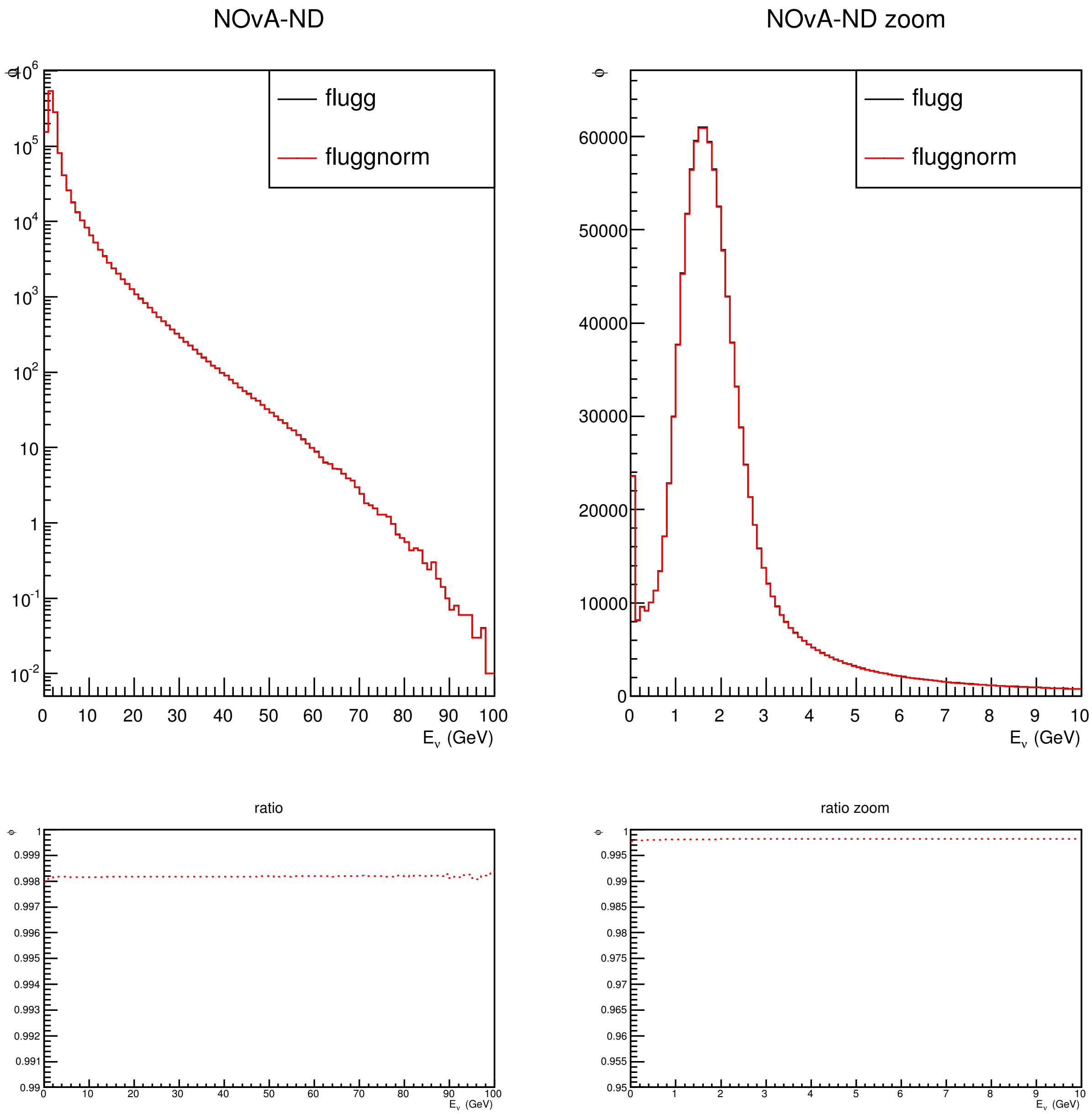


Figure 3: The effect on NOνA NDOS flux predictions. The lower plots are the ratio of the case where the effect is accounted for relative to the original code. The spikes (tagged with blue and green markers on the horizontal axis) are the energies of π and K decay at rest. Note the change in horizontal ranges compared to Figure 2.